C80/016EP

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 426 441 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 90311907.1

(22) Date of filing: 30.10.90

(51) Int. Cl.[5]: G02B 3/00, G02B 1/04, B29D 11/00

(30) Priority: 30.10.89 JP 283864/89
30.10.89 JP 283865/89
28.05.90 JP 138084/90
30.05.90 JP 142659/90

(43) Date of publication of application:
08.05.91 Bulletin 91/19

(84) Designated Contracting States:
DE FR GB NL

(71) Applicant: SHARP KABUSHIKI KAISHA
22-22 Nagaike-cho Abeno-ku
Osaka 545(JP)

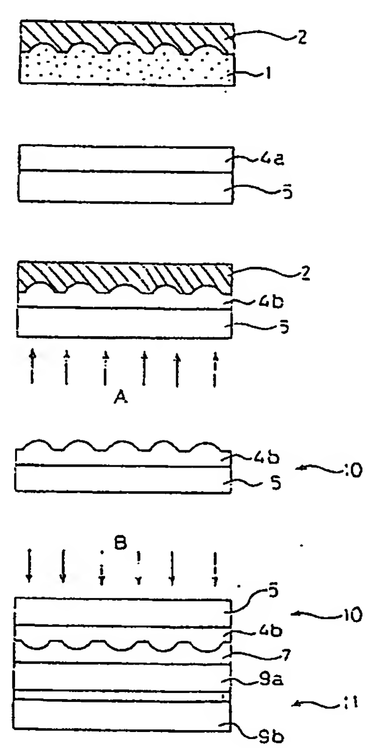
(72) Inventor: Watanabe, Noriko
5-8, Sanjosoekawa-cho
Nara-shi, Nara-ken(JP)
Inventor: Hamada, Hiroshi
7-177, Aoyama
Nara-shi, Nara-ken(JP)
Inventor: Funada, Fumiaki
33-10, Izumihara-cho
Yamatokoriyama-shi, Nara-ken(JP)

(74) Representative: Brown, Kenneth Richard et al
R.G.C. Jenkins & Co. 26 Caxton Street
London SW1H 0RJ(GB)

(54) **An optical device having a microlens and a process for making macrolenses.**

(57) An optical device having a lens substrate and a microlens portion formed thereon, wherein the microlens has its lens portion formed on the part of the optical device that has substantially the same coefficient of expansion as that of the lens substrate.

Fig. 1A
Fig. 1B
Fig. 1C
Fig. 1D
Fig. 1E



EP 0 426 441 A2

AN OPTICAL DEVICE HAVING A MICROLENS AND A PROCESS FOR MAKING MICROLENSES

BACKGROUND OF THE INVENTION

1. Field of the invention:

The present invention relates generally to the attachment of microlenses to an optical device, and to the production of microlenses to be attached to an optical device. More particularly, the present invention relates to an optical device having a microlens secured thereto, and to a process for producing microlenses for such use on a mass-production basis by use of a light-permissive die or stamper, hereinafter referred to as the "stamper".

2. Description of the prior art:

In this specification, the "microlens" means a lens of a size of not larger than a few millimeters, and also means a group of such microlenses which are arranged one-dimentionally or two-dimentionally. Hereinafter, these two types are generally referred to as "microlens".

The microlens can be used for various uses, for example:

(1) To intensify luminance by focusing light in areas around picture elements in non-luminant display devices such as liquid crystal devices, as disclosed in Japanese Laid-Open Patent Publications Nos. 60-165621 to 165624, and No. 60-262131.

(2) As light pick-up means such as laser disc, compact discs, and optical magnetic disc.

(3) As a focusing means for coupling a luminant device or a receptive device to an optical fiber.

(4) As a focusing means or an image forming means for focusing an incident light in a photoelectric converting zone so as to increase the sensitivity of a primary image sensor used in a solid-state image devices such as a CCD or facsimile machines (Japanese Laid-Open Publications Nos. 54-17620 and 57-9180).

(5) As an image forming means for forming an image on a sensitive medium to be printed by a liquid crystal printer or an LED printer (Japanese Laid-Open Publication No. 63-44624, etc.).

(6) As a filter for treating photo-information.

To make microlenses, the following processes are known:

(1) A substrate containing ions is submerged in a solution of alkaline salt, and ions are exchanged between the substrate and the salt solution through a mask formed on the substrate, thereby obtaining a substrate having a distribution of indexes of refraction corresponding to the pattern of the mask ("Ion Exchange Method" Applied Optics, 21(6), page 1052 (1984), Electron Lett., 17, page 452 (1981)).

(2) A photosensitive monomer is irradiated with ultra violet rays so as to polymerize an irradiat ed portion of the photosensitive monomer. Thus, the irradiated portion is caused to bulge into a lens configuration under an osmotic pressure occurring between the irradiated portion and the non-irradiated portion ("Process of Producing Plastic Microlenses" -24th Micro-Optics Meeting).

(3) A photosensitive resin is patterned into circles, and heated to temperatures above its softening point so as to enable the peripheral portion of each circular pattern to sag by surface tension, this process being referred to the "heat sagging process", ("Heat Sagging Process" by Zoran D. Popovic et al -Applied Optics, 27 page 1281 (1988)).

(4) A lens substrate is mechanically shaped into a lens (Mechanical Process).

A disadvantage common to these processes is that it requires several steps, therefore takes a relatively long time. As a result, they are not suitable for mass-production.

To achieve mass-production, an injection method employing a stamper made of metal such as nickel is proposed for molding plastic material into microlenses. However, the optical device having microlenses attached by this process has a disadvantage in that the microlenses are likely to separate from the optical device because of a difference in the coefficient of expansion, when the optical device is subjected to a rise in the ambient temperature.

There is another proposal for employing a stamper whereby a microlens is directly formed on an optical device. This process requires relatively high temperature and pressure. However, if such treatment is likely to damage the optical device that is normally liable to heat and pressure.

There is a further proposal for employing a metallic stamper that is applied to a photosensitive layer formed on the optical device so as to shape a lens configuration, and then the formed lens is allowed to harden under the irradiation of ultra violet rays. Under this process the ultra violet rays cannot be radiated from the side of the stamper but must be done from the side of the optical device. To effect the radiation of ultra violet rays through the optical device, the optical device should have a sufficient porosity to allow them to

pass. These considerations restrict the selection of a material of which optical devices are made.

SUMMARY OF THE INVENTION

The optical device of this invention, which overcomes the above-discussed and numerous other disadvantages and deficiencies of the prior art, comprises having a lens substrate and a microlens portion formed thereon, wherein the microlens has its lens portion formed on the part of the optical device that has substantially the same coefficient of expansion as that of the lens substrate.

In a preferred embodiment, the lens portion is made of photosensitive resin.

In another preferred embodiment, the microlens is attached to the optical device with an adhesive layer whose index of refraction has a different value from that of the lens portion.

According to another aspect of the present invention, there is provided a process for producing microlens for use in combination with optical devices, the process comprising the steps of forming a photosensitive resin layer on the optical device, applying a light-permissive stamper to the photosensitive resin layer so as to shape the photosensitive layer into a lens portion, and curing the lens portion under the irradiation of ultra violet ray through the stamper.

Thus, the invention described herein makes possible the objectives of (1) providing an optical device adapted for mass-production; (2) providing an optical device in which a microlens is secured irrespective of any changes in temperatures and any shock; and (3) providing a process for producing a microlens which enables microlenses to be directly formed on the optical device without damaging optical devices.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention may be better understood and its numerous objects and advantages will become apparent to those skilled in the art by reference to the accompanying drawings as follows:

Figures 1A to 1E are vertical cross-sectional views illustrating a series of steps for producing a first example of the embodiment according to the invention;

Figures 2A to 2E are vertical cross-sectional views illustrating a series of steps for producing a second example of the embodiment according to the invention;

Figures 3A to 3G are vertical cross-sectional views illustrating a series of steps for producing a third example of the embodiment according to the invention; and

Figures 4A to 4C are vertical cross-sectional views illustrating a process for shaping a stamper by a known sol-gel method.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1E shows the laminated structure of layers in a transmissive liquid crystal display apparatus **11**, hereinafter referred to as "display apparatus", including a microlens **10**. The microlens **10** includes a lens substrate **5** and a lens portion **4b** formed of a first photosensitive resin on the lens substrate **5**, and is bonded to a substrate **9a** of the display apparatus **11** with a second photosensitive resin layer **7**, that is, a bond layer. The substrates **9a** and **9b** are made of silica minerals such as silica glass. In the illustrated example, the substrate **5**, which has virtually the same coefficient of expansion as that of the lay ers **9a** and **9b**, are made of the same kind of silica minerals such as silica glass.

A process for making a microlens according to the present invention will be described with reference to Figures 1A to 1E:

At the stage of Figure 1A, a master **1** for the microlenses **10** was produced by a known heat sagging process, the microlens being a two-dimensional array which had a diameter of 38 μm, a radius of curvature of 72 μm, a central thickness of 3 μm, and an inter-lens distance of 42 μm. The microlens was designed so as to focus light to each picture element (not shown) arranged in a matrix. Then, the master **1** was coated with metal such as Ni and Cu by electrotyping so as to produce a stamper **2**.

At the stage of Figure 1B, the first photosensitive layer **4a** was formed about 100 μm thick on one of the sides of the substrate **5** of boro-silicate glass. This first photosensitive layer **4a** was later shaped into a lens portion **4b** as referred to below. The index of refraction of boro-silicate glass is 1.53, and therefore, as the first photosensitive resin, "NOA-61" manufactured by NORLAND Inc. (index of refraction is 1.56) was used because of the approximation in the index of refraction. Likewise, "AVR-100" and "TB-3003" manufactured by THREEBOND Inc., "UV-1003" manufactured by SONYCHEMICAL Inc., and "NOA-63" and "NOA-65" manufactured by NORLAND Inc. can be used as photosensitive resin.

At the stage of Figure 1C, the stamper **2** was pressed against the photosensitive resin layer **4a**

under irradiation of ultra violet rays (wavelength: about 300 to 400 nm) so as to shape it into the lens portion **4b** on the lens substrate 5. The ultra violet rays were radiated in the direction of arrows (A) toward the lens substrate **5**.

At the stage of Figure 1D the stamper 2 was released from the lens portion **4b**. In this way a microlens **10** was obtained.

At the stage of Figure 1E, the bond layer 7 (about 30 µm) was formed with a second photosensitive resin layer on the main substrate **9a** of the display apparatus **11**, and the microlens **10** was bonded to the substrate **9a** by means of the layer 7.

As shown in Figure 1E, the second photosensitive resin layer was irradiated with ultra violet rays (wavelength: about 300 to 400 nm) so as to harden the resin into the bond layer 7. The ultra violet rays were radiated in the direction of arrows (B) in Figure 1E.

For the second photosensitive resin layer, "AVR-100" manufactured by THREEBOND Inc. which had a smaller index of refraction (i.e. 1.46) than that of the first photosensitive resin was used to form the bond layer 7, and the microlens **10** was bonded to the display apparatus **11** in such a manner that the lens portion **4b** is faced thereto. Owing to the fact that the bond layer 7 was formed by the second photosensi tive resin layer 7 having a smaller index of refraction than that of the first photosensitive resin, the lens portion **4b** can function as a convex lens. If the two photosensitive resins had the same index of refraction, the microlens **10** would not function as a lens.

Referring to Figures 2A to 2E, a second example of the embodiment will be described:

As shown in Figure 2E, a microlens **20** used herein is formed by forming a concave lens portion **4b** on the substrate **5** made of boro-silicate glass of which the substrates **9a** and **9b** are also made.

A process of making the microlens **20** will be described:

At the stage of Figure 2A, a microlens portion **1a** is formed on a quartz glass substrate **1b** so as to form a master **1** for the microlens **20**. For a material for the microlens photoresist manufactured by a known heat sagging process can be used.

At the stage of Figure 2B the top portions of the microlens portion **1a** and the quartz glass substrate **1b** were eroded by a dry etching with a gaseous mixture of carbon tetrafluoride and oxygen.

The etching conditions such as the flow rate, the pressure and the mixing ratio (partial pressure ratio) of the gaseous mixture, the RF power and the temperatures of the substrate were adjusted to respective optimum values, thereby ensuring that the lens portion **1a** and substrate **1b** are uniformly etched. In this example, the microlens portion **1a** and the quartz glass **1b** were etched from the respective tops by a greater thickness than the microlens portion **1a** under such conditions that the ratio to be selected become equal to each other. Then, the configuration of the microlens **1a** was transferred to the quartz substrate **1b**. In this way a convex stamper **2** was obtained.

The sampler **2** can be used as a convex microlens or may be used as a master for making a concave microlens.

At the stage of Figure 2c, a first photosensitive resin layer **4a** on a substrate **5** of boro-silicate glass which is the same material for the substrate **9a** and **9b** used in the display apparatus **11**. Then, the sequence advances to the next step of Figure 2D, where the convex stamper **2** was applied to the first photosensitive resin layer **4a** irradiated with ultra violet rays was shaped and cured, thereby forming a convex lens portion **4b** on a glass substrate **5**. Ultra violet ray can be radiated in either direction of arrow (C) or (D). At the stage of Figure 2E the stamper **2** was removed from the lens portion **4b**, thus obtaining a concave microlens **20**.

The microlens **20** is attached to the display apparatus **11** by forming a bond layer **7** (second photo-sensitive layer) on the substrate **9a** and radiating ultra violet rays upon the bond layer **7** so as to secure light-curing. The microlens **20** functions as a convex lens but if it is intended to enable the microlens **20** to function as a convex lens, the second photosensitive resin should have a larger index of refraction than that of the first photosensitive resin. In the illustrated embodiment, "AVR-100" (index of refraction: 1.46) manufactured by THREEBOND Inc. was used for the first photosensitive resin, and "NOA-61" (index of refraction: 1.56) manufactured by NORLAND Inc. was used for the second photosensitive resin.

In the illustrated embodiments the microlens **10** and **20** were attached to the display apparatus **11** in such a manner that the lens portions **4b** were in contact with the bond layer **7**, thereby shortening the intervals between the picture elements in the display apparatus **11** and the lens portion **4b** of the microlens **10** and **20**. The shortened interval between the picture elements and the lens portion **4b** allows the focal distance to be short, thereby ensuring that light is focused within the picture elements.

In the first example described above, the bond layer **7** was about 30 µm thick, and the substrate **9a** was 1.1 mm thick. In order to focus light within the picture elements in the display apparatus **11**, the microlens **10** is designed to ensure that the focal length f should be 1.1 mm in the glass substrate. In this case, the thickness of the bond layer **7** is much smaller than that of the substrate

9a, and therefore, the focal length f is expressed by the following equation (1):

$f = r \cdot n3 / (n1 - n2)$ (1) where

r : the radius of curvature of the microlens **10**

n 1: the index of refraction of the lens portion **4b** - (lst photosensitive resign)

n 2: the index of refraction of the bond layer **7** (2nd photosensitive resin layer)

n 3: the index of refraction of the substrate **9a**

The value of the following theorem (2) is obtained by multiplying the equation (1) by a coefficient (n 3/n 2) which is used to convert the focal length f1 into a focal length in the medium 3 (index of refraction: n 3):

$f1 = r \cdot n2 / (n1 - n2)$ (2)

The theorem (2) is to obtain the focal length f1 in the interface between medium 1 (index of refraction: n 1) and medium 2 (index of refraction: n 2).

The following values are placed in the equation (1):

$n1 = 1.56$

$n2 = 1.46$

$n3 = 1.53$

$r = 72\ \mu m$ (radius of curvature of the microlens **10**

Thus, the focal length = 1.1 mm

It will be appreciated from this calculation that the light is focused on the picture elements in the display apparatus **11** through the microlens **10**, the bond layer **7** and the substrate **9a**.

In the illustrated embodiments, the substrates **5** of the microlenses **10** and **20** are made of boro-silicate glass as the substrate **9a** of the display apparatus **11** is. The microlens **10** and **20** are respectively bonded to the substrate **9a** of the display apparatus **11** through the bond layer **7** having a different index of refraction from that of the lens portion **4b**. The lens portion **4b** is formed on the substrate **5** by pressing a photosensitive resin layer **4a** overlaying the substrate **5** by the stamper **2** under the irradiation of ultra violet rays. The following advantages result:

(1) The lens portion **4b** of the microlenses **10** and **20** are formed on the substrate **5** made of the same material as that of the substrate **9a** of the display apparatus **11**, which means that they have the same coefficient of expansion, thereby preventing any detrimental separation from occurring between the microlens **10**, **20** and the substrate **9a** in response to changes in the ambient temperature. Since the lens portion **4b** is made of the same material as that of the bond layer **7**, they are sufficiently affiliated, thereby securing the bond between the microlenses **10**, **20** and the substrate **9a**.

(2) Since the bond layer **7** has a different index of refraction from that of the lens portion **4b**, whereby the microlenses **10** and **20** are respectively bonded to the substrate **9a** of the display apparatus **11**, the microlenses **10** and **20** can function without being affected by the fact that the lens portion **4b** is bonded to the substrate **9a** of the display apparatus **11**. This effect allows the lens portion **4b** to be disposed in opposition to the substrate **9a**, thereby shortening the focal length of the microlenses **10** and **20**. Thus, the focusing strength of the lenses **10** and **20** is enhanced.

(3) The light is focused on the picture elements in the display apparatus **11**, thereby increasing the effective porosity of the display apparatus **11**. This enhances the luminance of the display apparatus **11**, thereby securing clear image pictures on the screen.

(4) The use of the stamper **2** shortens the time required for shaping the microlens **10** and **20**, thereby increasing the mass-productivity and decreasing the production cost.

(5) The lens portion **4a** is formed by shaping a softened photosensitive layer **4a** by use of the stamper **2**, and after hardening, the shaped lens portion **4b** is readily released from the stamper **2** preferably with the use of a lubricant.

The application of the optical device equipped with a microlens according to the present invention is not limited to the display apparatus **11**, but can be made to any other optical apparatus, provided that the substrates of the microlenses **10** and **20** are respectively made of a material having the same coefficient of expansion as that of the object to which the microlenses **10** and **20** are bonded.

Referring to Figures 3A to 3G, a third example will be described:

In this example, a microlens **30** was directly bonded to a display apparatus 3 I of a light transmission type.

A mold **21** was made by a conventional heat sagging process, from which a stamper **26** was made. The process will be more specifically described:

At the stage of Figure 3A, the mold **21** is coated with metal such as copper or nickel by electrotyping, so as to obtain a master **22**. The master **22** can be mechanically produced of metal.

At the stage of Figure 3B, the master **22** is coated with metal such as nickel or copper by electrotyping. In this way a mother **23** was obtained.

Then, a photosensitive layer **24** (about 100 μm thick) was formed on one side of the boro-silicate glass substrate **25**, of which the substrates **29a** and **29b** were also made.

At the stage of Figure 3C, the mother **23** was applied to the photosensitive resin layer **24** under the irradiation of ultra violet rays (wavelength: about 300 to 400 nm). Thus, the photosensitive resin layer **24** was formed and cured. The ultra violet rays was radiated in the direction of arrows (A) through the glass substrate **25** which allows the

ultra violet rays to pass.

At the stage of Figure 3D, the mother **23** was removed from the photosensitive layer **24**. In this way the stamper **26** was obtained. Since the stamper **26** was composed of the hardened photosensitive resin layer **24** and boro-silicate glass substrate **25**, it allows ultra violet rays to pass.

The stamper **26** can be made by other methods. For example, photosensitive resin can be poured into the mother **23** without the use of the boro-silicate glass substrate **25** under the irradiation of ultra violet rays so as to make it hard. Alternatively, instead of using the photosensitive resin layer **24**, a resin layer can be formed on the boro-silicate glass substrate **25**, wherein the resin material can be any kind if it is capable of hardening at a room temperature, and allows ultra violet ray to pass after becoming hardened, and the mother **23** can be applied thereto to obtain the stamper **26**. Another alternative method is to inject a light-permissive substance such as polystyrene, acrylic resin, poly-vinyle chloride, polycarbonate and glass, and mold it into the stamper **26** by use of an extruding machine.

The stamper **26** can be also made by a sol-gel method. The advantage of this method is that a clear stamper **26** can be obtained directly from the master 21. Referring to Figures 4A to 4C, the sol-gel method will be described:

At the stage of Figure 4A, a sol 32 of metallic alkoxide was obtained by adding water, ethyl alcohol, and a catalyst to ethyl silicate with the addition of polyethylene glycol whereby the sol becomes soft, and the sol **32** was coated on the glass substrate **25**. At the stage of Figure 4A, while the sol **32** was soft, the master **21** was applied to the sol **32** so as to shape it into a lens portion.

At the stage of Figure 4B, the lens portion was treated at not higher than 500°C in a furnace **33**. In this way the stamper **26** was obtained at the stage of Figure 4C.

The sol-gel method includes the process of heat treatment, and the injection molding method also includes the process of heating at which the material is molten and molded. It is required to design the master **21** previously by taking into consideration a dimensional difference likely to occur when the stamper **26** cools to room temperature.

After the stamper **26** was obtained, a photosensitive layer **28** was formed about **100** µm thick on the substrates **29a** or **29b** of the display panel **31** at the stage of Figure 3E. The photosensitive resin having an index of refraction near to that (i.e. 1.53) of boro-manufactured by NORLAND Inc. having an index of refraction of 1.56 was used. It has been found that "AVR- 100" and "TB-3003" manufactured by THREEBOND Inc., "UV-1003" manufactured by SONYCHEMICAL Inc., and "NOA-63" and "NOA-65" manufactured by NORLAND Inc. could be effectively used.

At the stage of Figure 3F, the stamper **26** was applied to the photosensitive resin layer **28** so as to shape it into the microlens **30**, which was then irradiated with ultra violet rays (wavelength: about 300 to 400 nm) through the stamper **26**, thereby curing the photosensitive resin layer **28**. The ultra violet rays were radiated in the direction of arrows (B) (Figure 3F) through the stamper **26**.

The stamper **26** was removed. In this way the microlens **30** was shaped as shown in Figure 3G. Preferably, a silicon-base lubricant is coated on the inner surface of the stamper **26** before the stamper **26** is applied to the photosensitive resin layer **28** so as to enable the stamper **26** to be easily removed from the photosensitive resin layer **28**.

The third example has the following advantages:

(1) The use of the stamper **26** shortens the time required for shaping the microlens **30**, thereby increasing the mass-productivity and decreasing the production cost.

(2) Owing to the direct bond of the microlens **30** to the substrate **29a** of the display panel **31**, the bond between the microlens **30** and the substrate **29a** is accordingly secured.

(3) The process of shaping the microlens **30** includes no process of applying heat or pressure, thereby making it possible to form the microlens **30** on the display panel **31** without the possibility of damaging the display apparatus **31** by heat.

(4) Ultra violet ray can be radiated through the stamper 26 from the side of the display panel **31** because it is made of a material allowing light to pass. If a conventional stamper made of a non-transparent material is used, ultra violet rays must be radiated through the display panel **31**. When the black matrices are disposed in the display panel **31** so as to shield light against between the picture elements, the amount of ultra violet light passing therethrough is accordingly reduced. To compensate for the loss of ultra violet ray, the irradiation of it must be strengthened and prolonged to cure the photosensitive resin layer **28** sufficiently. If an excessively strong ultra violet ray is radiated through the display panel **31**, the liquid crystal therein is likely to be degraded. The present invention has solved these problems.

(5) The light is focused on the picture elements in the display panel **31**, thereby increasing the effective porosity of the display panel **31**. This enhances the luminance of the display panel **31**, thereby securing clear image pictures on the screen.

In the third example, the microlens (microlens array) having a focal length of 1.1 mm, and a diameter of about 90 µm was formed on the display panel 31 but its dimension can be variously changed in accordance with the size of the display panel.

The microlens can be applied to any other optical apparatus in addition to the liquid crystal display panel.

It is understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be construed as encompassing all the features of patentable novelty that reside in the present invention, including all features that would be treated as equivalents thereof by those skilled in the art to which this invention pertains.

There are described above novel features which the skilled man will appreciate give rise to advantages. These are each independent aspects of the invention to be covered by the present application, irrespective of whether or not they are included within the scope of the following claims.

Claims

1. In an optical device having a lens substrate and a microlens portion formed thereon, wherein the microlens has its lens portion formed on the part of the optical device that has substantially the same coefficient of expansion as that of the lens substrate.
2. An optical device according to claim 1, wherein the lens portion is made of photosensitive resin.
3. An optical device according to claim 1 or 2, wherein the microlens is attached to the optical device with an adhesive layer whose index of refraction has a different value from that of the lens portion.
4. A process for producing microlens for use in combination with optical devices, the process comprising the steps of forming a photosensitive resin layer on the optical device, applying a light-permissive stamper to the photosensitive resin layer so as to shape the photosensitive layer into a lens portion, and curing the lens portion under the irradiation of ultra violet rays through the stamper.
5. An optical apparatus (10, 11, 20, 11) comprising a refractive index distribution microlens array (10, 20) having a plurality of microlenses for converging incident light to a plurality of regions of an optical device (11) to which the microlens array is attached, characterised in that the microlens array is provided in a microlens portion (4b) attached on its side remote from the optical device to a lens substrate (5) having substantially the same coefficient of expansion as that of a portion (9a) of the optical device to which the microlens portion is attached.
6. An optical apparatus comprising a refractive index distribution microlens array having a plurality of microlenses defining one surface of a microlens portion (4b) characterised in that said one surface is attached to an optical layer (9a) of an optical device (11) by an adhesive layer (7) having a refractive index different in value to that of the microlens portion (4b).
7. An optical device according to claim 5 wherein the microlens array defines one surface of the microlens portion (4b) and wherein said one surface is attached to the optical layer (9a) by an adhesive layer (7) having a refractive index different in value layer (7) having a refractive index different in value to that of the microlens portion (4b).
8. An optical device according to claim 6 or 7 wherein the microlens portion (4b) comprises an array of convex lenses and the refractive index of the adhesive layer (7) is smaller than the refractive index of the microlens portion.
9. An optical device according to claim 6 or 7 wherein the microlens portion comprises an array of concave lenses and the refractive index of the adhesive layer (7) is greater than the refractive index of the microlens portion (4b).
10. A stamper (26) for shaping a photosensitive layer to provide a microlens array characterised in that the stamper is light-permissive.
11. A method of forming an optical device having a lens substrate (5) and a microlens portion (4b) comprising the steps:
stamping a photosensitive layer (4a) to provide a surface defining a microlens array;
curing the photosensitive layer; and
adhering said surface of the microlens array to a portion (9a) of an optical device (11) using an adhesive layer (7) having a refractive index different to that of the photosensitive layer.
12. A method according to claim 11 wherein the photosensitive layer (4a) is disposed on a lens substrate (5) having a coefficient of expansion substantially the same as that of the portion (9a) of the optical device (11).
13. A process for producing microlens for use in combination with optical devices, the process comprising the steps of forming a photosensitive resin layer on the optical device, applying a light-permissive stamper to the photosensitive resin layer so as to shape the photosensitive layer into a lens portion, and curing the lens portion under irradiation through the stamper.

Fig. 1A

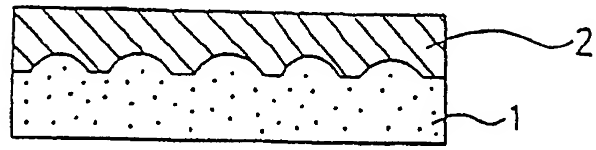


Fig. 1B

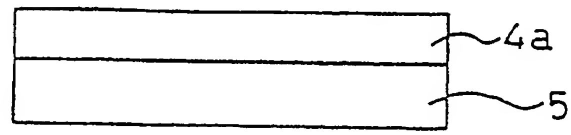


Fig. 1C

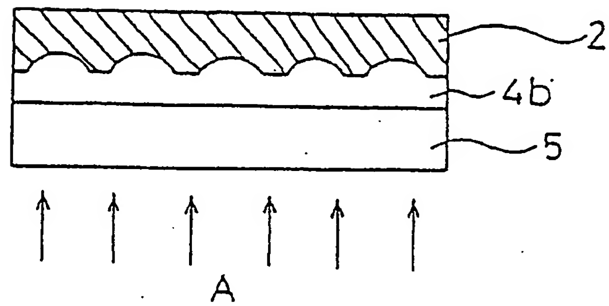


Fig. 1D

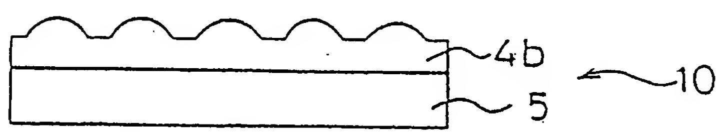


Fig. 1E

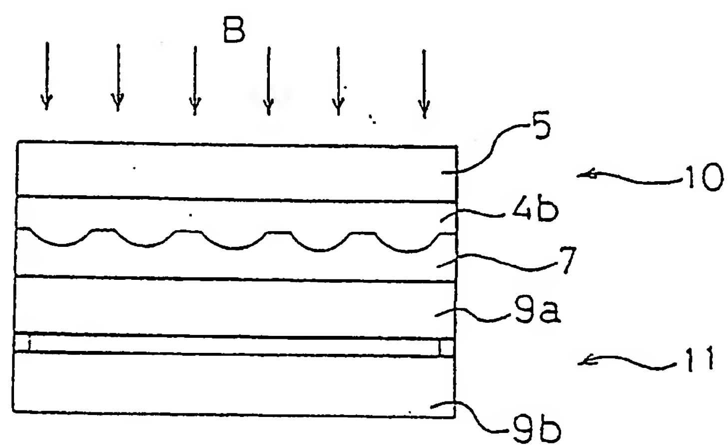


Fig. 2A

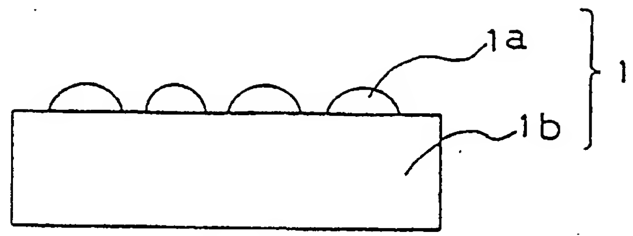


Fig. 2B

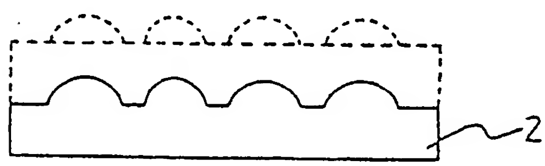


Fig. 2C

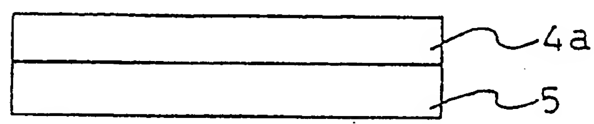


Fig. 2D

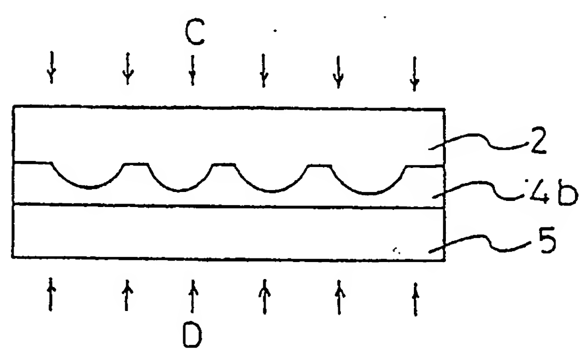


Fig. 2E

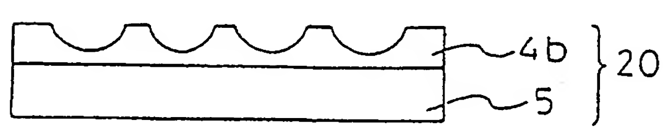


Fig. 3A

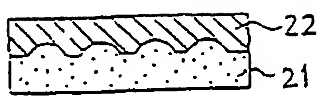


Fig. 3B

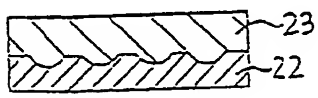


Fig. 3C

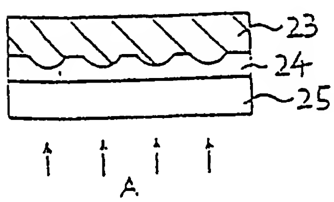


Fig. 3D

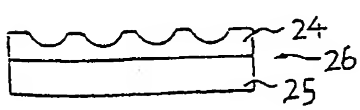


Fig. 3E

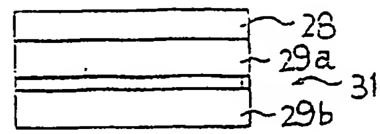


Fig. 3F

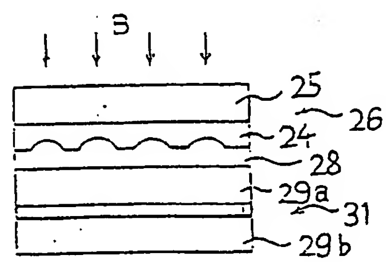


Fig. 3G

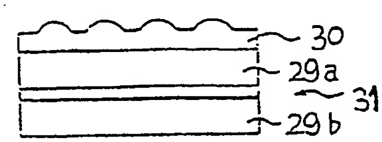


Fig. 4A

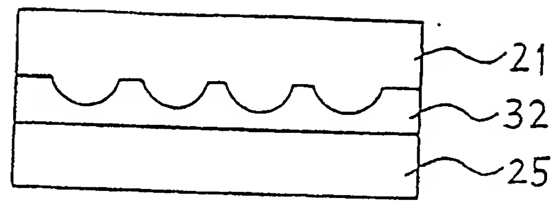


Fig. 4B

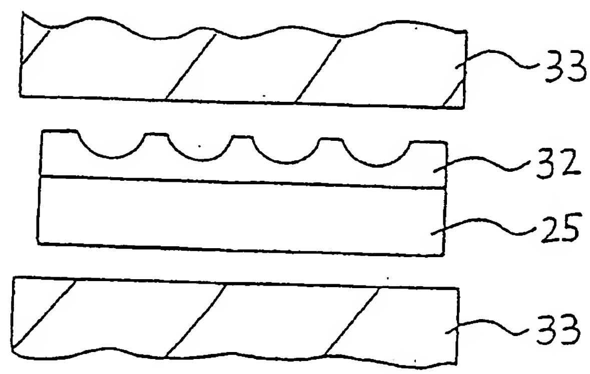


Fig. 4C